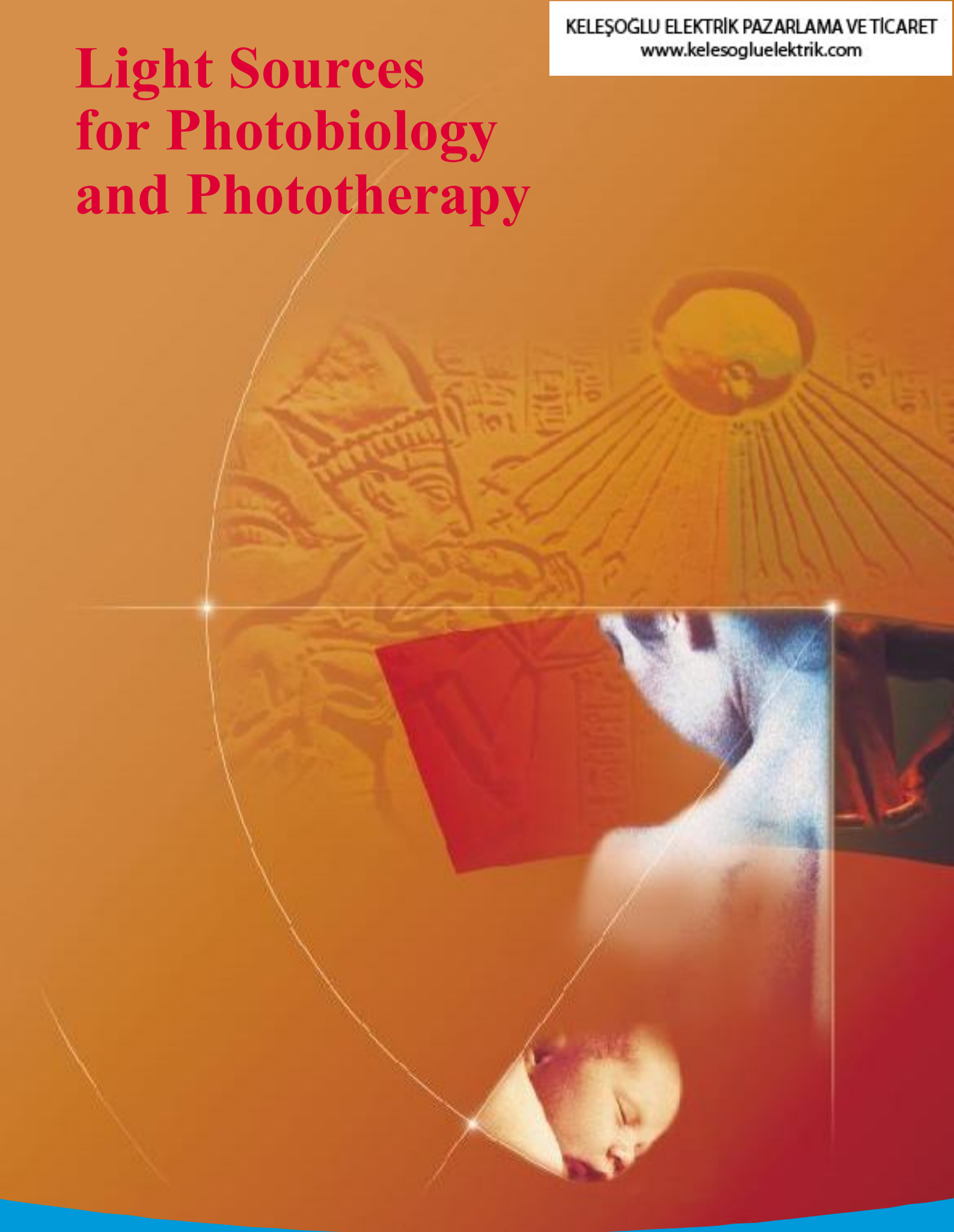
Light Sources for Photobiology and Phototherapy



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PREFACE

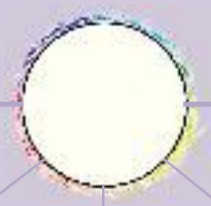
For more then 100 years, PHILIPS has been one of the pioneers in lighting. Today, as the world's largest manufacturer of lighting products, we employ a wealth of experience to satisfy lighting requirements for a multitude of applications.

For photobiological and therapeutical purposes, PHILIPS LIGHTING can provide a broad variety of lamps. Our application laboratory carries out research in close cooperation with universities and clinics throughout the world. Based on this unmatched combination of experience and knowledge, PHILIPS LIGHTING can offer the best advice to equipment manufacturers on any possible application.

P H I L I P S L I G H T I N G w i l l b e t h e i d e a l p a r t n e r .

This publication provides a review of the history and the current state of affairs regarding photomedical applications and a summary of the products now available.

There is always the possibility that new products emerge from the close cooperation between science and research and lamp manufacturers. The more accurately the application, its action spectrum or the dosage is defined, the better the light source can be optimized as to its efficacy and economy.



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THE HUMAN BEING AND SUNLIGHT IN HISTORY

Far back in history, sun was considered a source of life. Indeed, it was often elevated to the status of a god and men believed in the healing powers of its rays. All over the world evidence has been found of cults worshipping sun-gods. In ancient history the sun worship of the Pharaoh Ikhnaton (1350 B.C.) was very important. He built temples dedicated to the light god, Aton. These temples were very unusual for the time as they had no roof, so the sunlight could freely fill the space inside. As an example to their co-religionists, Ikhnaton and his family took off their clothes to benefit from the healing effects of the rays of the sun. The priests of the time remained rather sceptical about this “enlightened” religion of Ikhnaton. It flourished at the expense of their mystical and darker cults. After the death of Ikhnaton, the sun temples were soon pulled down. However, “sunbathing” continued to exist through the centuries in Egypt. The historian Herodotus (5th century B.C.) found this so remarkable that he described it in his chronicles: “The health-promoting properties of sunlight have been recognised from the beginning of civilization as a natural intuitive desire which causes humans, when in poor health, to be attracted by our largest optical radiation source: the sun". In these early times, phototherapy (heliotherapy) was born and guided by experience rather than any scientific basis for the treatment of certain ailments.

The Greek doctor and “father” of medical science Hippocrates (born in 460 B.C. on the island of Cos) had, on his many travels in Egypt, studied the sunlight treatment which was practised there. On his return to Greece, he set up a clinic and medical school on the island of his birth thus breaking away from the medicine as practised at the time by the priests. He was practising medicine for the first time as a real empirical science. He wrote many books on the surgery of fractures, hygiene and diets. In his sanatorium with its open gallery facing south he treated patients on a scientific basis. He is, with good reason, considered to be the father of light therapy.

Later the Greeks and Romans continued this light therapy, otherwise known as heliotherapy. Very well known from this time are the Roman baths (therms), where it was also possible to sunbathe in a solarium. The concept of the solarium dates from this time, indicating that use was being made of natural sunlight. In our time, with the word solarium we refer to the use of an artificial sun, i.e. equipment containing special lamps.
With the decline of the Roman Empire, heliotherapy disappeared. In the Dark Ages and with the spread of Christianity, medicine and hygiene reached a very low ebb creating a situation where epidemics of cholera, plague and smallpox could easily break out. With the rise of Christianity every form of attention to the body and display of nakedness was considered sinful. All baths disappeared from houses and bath houses were closed.

The Swiss Arnold Rikli (1823-1906) reintroduced the positive effects of sunlight which had been forgotten for many centuries and used these effects as the basis of successful natural healing methods - he practised for more than 50 years. He was responsible for developing therapeutic guidelines and ideas which are still valid today. His motto "Water is good, air is better and light is best of all" is the basis of heliotherapy.

The Danish doctor Niels Ryberg Finsen (1860-1904) has initiated an emphatic rebirth of light therapy in 1898. In that year he established a sun garden in Copenhagen (attached to the Finsen Institute) for his patients, where they could sunbathe completely naked. At the start, only natural sunlight was used, but because sunlight at this latitude (55°N) is not so plentiful, he soon changed over to the use of artificial light sources. Consequently he discovered that the ultraviolet part of the sunlight spectrum has a beneficial influence on the human body.
In 1893 he demonstrated that red light was beneficial for healing the skin of smallpox patients. With artificially generated ultraviolet rays he could cure patients suffering from skin tuberculosis. In 1903, one year before his death, he received the Nobel Prize for Medicine.
In the following chapters we shall see that not only the effects of ultraviolet rays but also the effects of visible and infrared rays can be beneficial. It is clear that in the millions of years of evolution our bodies have become adapted and make use of the complete scolar spectrum to regulate various body functions. The beneficial effects of ultraviolet rays were researched and valued much more in East European countries, such as Russia, than in the Western medical world. It is a great pity that in our Western societies attention is given almost exclusively to the negative effects of solar radiation. These negative acute and chronic effects only occur when the body is excessively exposed to this radiation. In general, mention is not made of the great benefits of UV radiation which can be received in full measure when it is used in moderation. An important reason for this is that illnesses which were previously cured with the help of UV radiation are now treated with drugs and antibiotics. An example of this is skin tuberculosis (lupus vulgaris) which was formerly treated (discovered by Finsen) with UV radiation. This was later replaced by drugs and so treatment with ultraviolet radiation was quickly forgotten. With the present rapid increase in the use of medicines and the many objections which this has given rise to, the prophylactic and therapeutic effects of optical radiation deserve to receive much more attention.

In view of the long history of the relationship between man and the sun's rays, in this brochure written in a non-technical style,we are trying to create more interest in the positive effects of non-visual optical radiation.
Since prehistoric times the evolution of all life on earth has taken place under the radiation of the sun. The sun can be regarded as an indispensable environmental factor in regulating our genetic material, biological rhythms and, in a broad sense, many photobiological processes via the skin and the eyes (neuroendocrine systems).
What we know today about these photobiological processes is certainly only the tip of the iceberg.

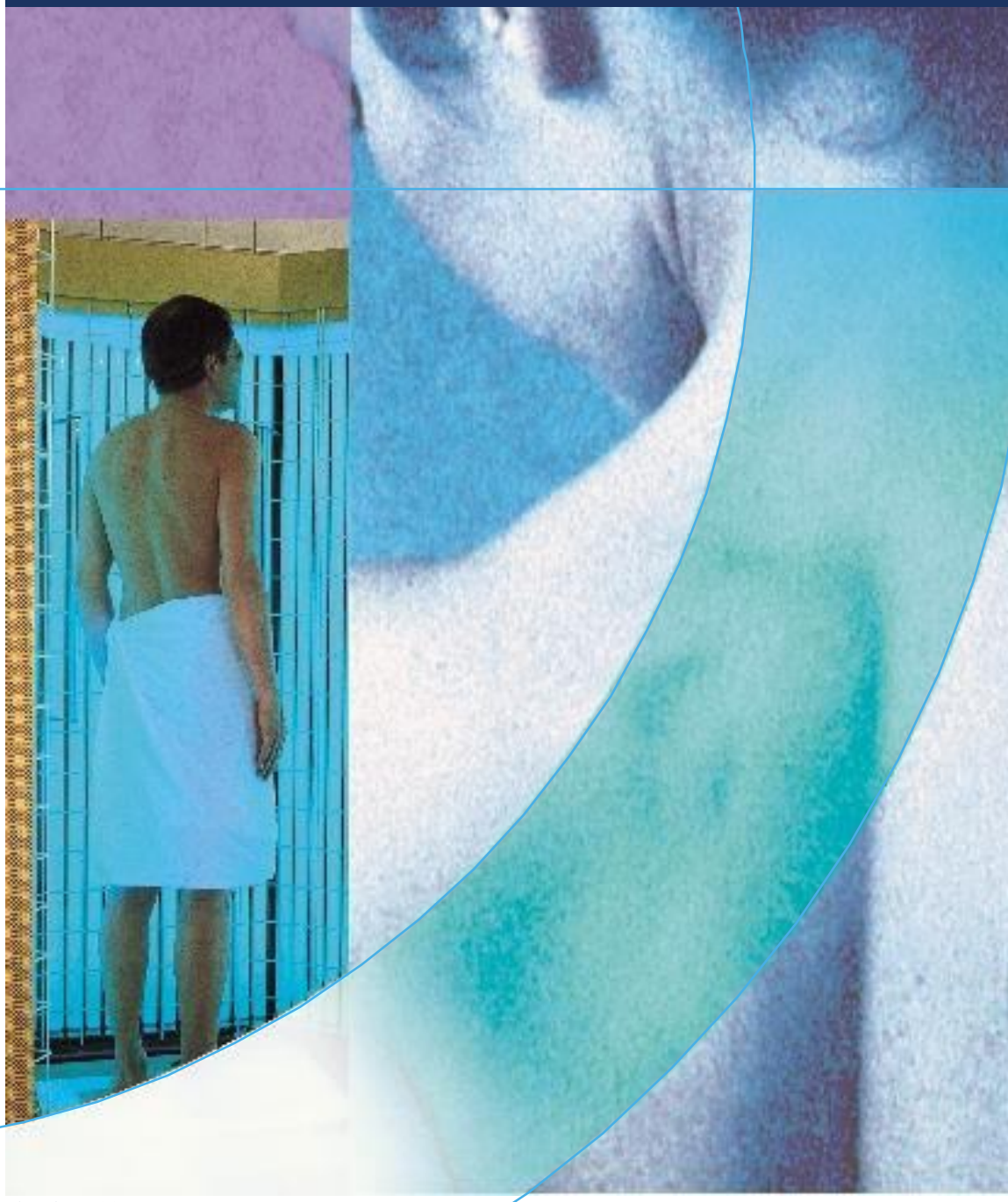
3 LIGHT IN PREVENTION, THERAPY AND REHABILITATION

Nowadays, prevention, phototherapy and rehabilitation with optical radiation are the result of clinical studies guided by the progress in physics, chemistry and molecular photobiology. Much more of what happened during earlier centuries is now understood in detail.

Modern photomedicine started about 100 years ago with the already mentioned publication (1899) of Niels Finsen (1) in which he described the treatment of lupus vulgaris by ultraviolet radiation. At that time Finsen's results were attained by the rays of a strong carbon arc. Now, after 100 years of development, more sophisticated lamps are available for therapeutic and prophylactic purposes.

Knowledge as the fundamental basis

The past 15 years have seen a large number of publications concerning photobiological research and photomedicine; this reflects the expanding potential of optical radiation for prevention, therapy and rehabilitation (16). Of course, adequate knowledge and experience with handling optical radiation (ultraviolet, visible light and infrared) are essential if full advantage is to be taken of all potential uses. The aim is always to maximise the benefit whilst minimising the level of risk. The correct dosage is the most important step. This means that therapy must always be carried out under the supervision of a doctor.



In the sixties, in a previous Philips brochure (2), H.A.W. Klinkhamer (General Practitioner) listed complaints which could be treated with “light”. It will be very instructive to first categorize these complaints according to the light applied and then see what the state of the art at this moment is.

For treatment with ultraviolet “light”, Klinkhamer listed the following complaints:

a. Prevention: rachitis, winter-fatigue, asthenic children, anaemia.
b. Infectious diseases: lupus vulgaris, various types of eczema, bronchitis.
c. Allergic diseases: neurodermatitis, asthma bronchiale.
d. General rehabilitation.
e. Skin diseases: alopecia areata (hair disease), acne vulgaris and psoriasis.

Light protection

It is one of the most important functions of the skin to build up its own light protection. Melanogenesis, pigment darkening and skin thickening can be activated along with lesion, provided there is an individual (genetic) disposition (in Caucasian skin-types 2 to 4). As a consequence, the period of auto-protection changes. The UV dosage must be in line with individual response and sensitivity according to skin-type. Depending on the quality (spectrum) and the quantity (dose) of UV, a sun protection factor (SPF) of 4 to 8 can be obtained for instance with a sun-bed equipped with CLEO Professional.

Psoriasis
Psoriasis is a (primarily) genetically determined and chronic skin disease which affects 2% of all light-skinned people. It is one of the few diseases which is still incurable; moreover, no effective chemotherapy without side effects has yet been discovered for treating such diseases. (Photo-) chemotherapy is one way of treating the disorder with a high success rate.

- PUVA photochemotherapy
A new era in therapeutic photomedicine was initiated at the start of the 1970's when, on the basis of research work carried out in USA and Austria, Parrish et al. (3) described the systemic treatment of psoriasis by psoralens and irradiation with UV-A, so-called PUVA therapy.
At this time the concept of photochemotherapy was introduced. In photochemotherapy the combination of a photosensitizing chemical compound and optical radiation is used to bring about a therapeutically beneficial result not produced by either the radiation or a drug alone. The drug may be applied topically or orally to reach the skin by blood circulation and is subsequently activated by irradiation with UV-A.

In practice, PUVA photochemotherapy is not only used for the treatment of psoriasis but for many other skin diseases as well (being in common use for more than 20 indications at present). It is applied by using a UV-sensitizing medicine and combining it with UV-A lamps (CLEO Performance and sometimes filtered HPA).
The natural, UV-sensitizing psoralenes (8 MOP, 5 MOP or others) are available in the market under various brand-names.

Recently it has been found that chronic and high dosage use of PUVA chemophototherapy in the treatment of psoriasis has serious negative side effects. Under the conditions indicated the application of PUVA increases the risk of obtaining skin cancers like malignant melanoma. As a consequence there is a shift in preferred treatment protocols in favour of TL/01 phototherapy (18).

-SUP phototherapy
Phototherapy of psoriasis (SUP = selective UV phototherapy) or other diseases of the skin is a type of therapy (with UV-B) without any photo-sensitizing agent. It is the oldest form of treatment, and it is based on the experience with the favourable effects of sunlight on the general appearance of the skin.
Numerous investigations show (4, 5, 6, 7, 8) that phototherapy with UV-B is just as effective as PUVA therapy if the right doses are maintained. Another critical parameter is the UV-B wavelength applied. Various investigations imply that the most favourable range for the effective UV-B treatment of psoriasis is in the long-wave part of the UV-B spectrum (between 305 and 315 nm). This warrants a high (therapeutical) efficiency on the one hand and minimum (acute and chronic) risks on the other.

There are mainly two types of fluorescent lamps of different spectral distribution - the TL/01-UVB narrow-band and the TL/12 UVB broadband lamp - available for SUP therapy of psoriasis. The erythemal effect of the radiation from the TL/01 lamp is much smaller than from the TL/12 lamp so that - with the aim of being able to irradiate as much UV-B as possible without producing erythema (reddening of the skin) - the TL/01 is a better proposition. Moreover, recent investigations show that for successful therapy,TL/01 radiation can be dosaged far below the erythemal threshold. This makes the period of exposure shorter, reducing overall dosages and thus any acute or chronic side-effects.
TL/01 lamps have been tested world-wide in extensive clinical tests and are universally in practical use. Irradiation equipment involving TL/01 lamps supply good means of home therapy as dosage can be easily controlled. The therapy schedule is drawn up by the doctor (adjustment of the individual sensitivity of the patient to the irradiation quality and quantity of the equipment) who will verify its success at regular intervals. Once the patient shows no symptoms any more a conservative therapy (possibly combined with a psychosomatic treatment) with individually adjusted doses presents no problem.

-Balneo-phototherapy
The positive experience with the treatment of psoriatics at the Dead Sea is being increasingly transferred to clinical treatment. Brine baths, with a simultaneous or subsequent exposure to UV-B (using TL/01) provide better results at a generally lower dosage that in SUP phototherapy. This is mainly attributed to the greater transparency of wet skin. Balneo-phototherapy of psoriaris is successfully applied for in-patients in numerous spas; it is also applied for out-patients in therapeutic centres.

Atopic dermatitis
Atopic dermatitis (atopic eczema, neuro-dermatitis) is a constitutional, inflammatory skin disease, usually progressing chronically. In the majority of patients, UV irradiation proves favourable. The active spectrum is mostly in the UV range, between 300 and 400 nm (equipment with TL/10, CLEO Performance, CLEO Natural, HPA filtered). The dosage (quality and quantity of radiation) has to be adjusted to the individual response of the patient and possibly (in case of a reaction of adaptation) be altered in the course of the therapy.

Acne
Acne vulgaris is a chronic skin disorder caused by inflammation (propionibacterium acnes) of the skin glands and hair follicles mainly of the face, chest and shoulders and is chiefly found in adolescents. All types of radiation may be applicable and lead to improvement: UV-B and UV-A radiation as well as intensive visible radiation (light in the blue and green wavelength range with 'TL'/03, 'TL'/52, TL'/17 or filtered metal iodide lamps which are doped with indium or gallium), depending on the type of acne and the reaction of the individual patient (9).

Other skin diseases
Psoriasis, being a genetically chronic skin disorder which affects about 2% of Caucasians, and vitiligo, being an acquired amelanosis which affects a similar percentage of the dark-skinned population, are always put at the forefront. But the list of other skin diseases which can be treated with photo(chemo)therapy is constantly growing. Many complaints listed by Klinkhamer can still be treated by infrared and ultraviolet light, but it is evident that a disease like lupus vulgaris is optimally treated with chemotherapy. Some other dermatoses responsive to photo(chemo)therapy are parapsoriasis, vitiligo, cutaneous T-cell lymphoma (Sezary syndrome), mycosis fungoides, lichen planus, pityriasis lichenoides, pityriasis rosea, various types of eczema, polymorphous light eruption, furunculosis, folliculitis, indolent ulcers, prurigo and pruritis, etc.

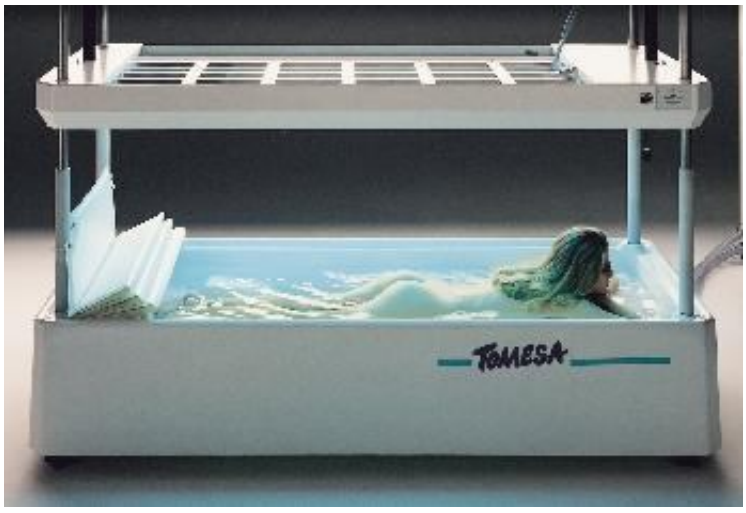
It has also been stated that exposure to ultraviolet "light" causes an exacerbation or produces injurious effects in the following conditions: xeroderma pigmentosum, herpes simplex, lupus erythematosus, serveral types of eczema, prematurely senile skin, porphyria, with the use of immunosuppressive medications (after kidney transplants) and Aids.

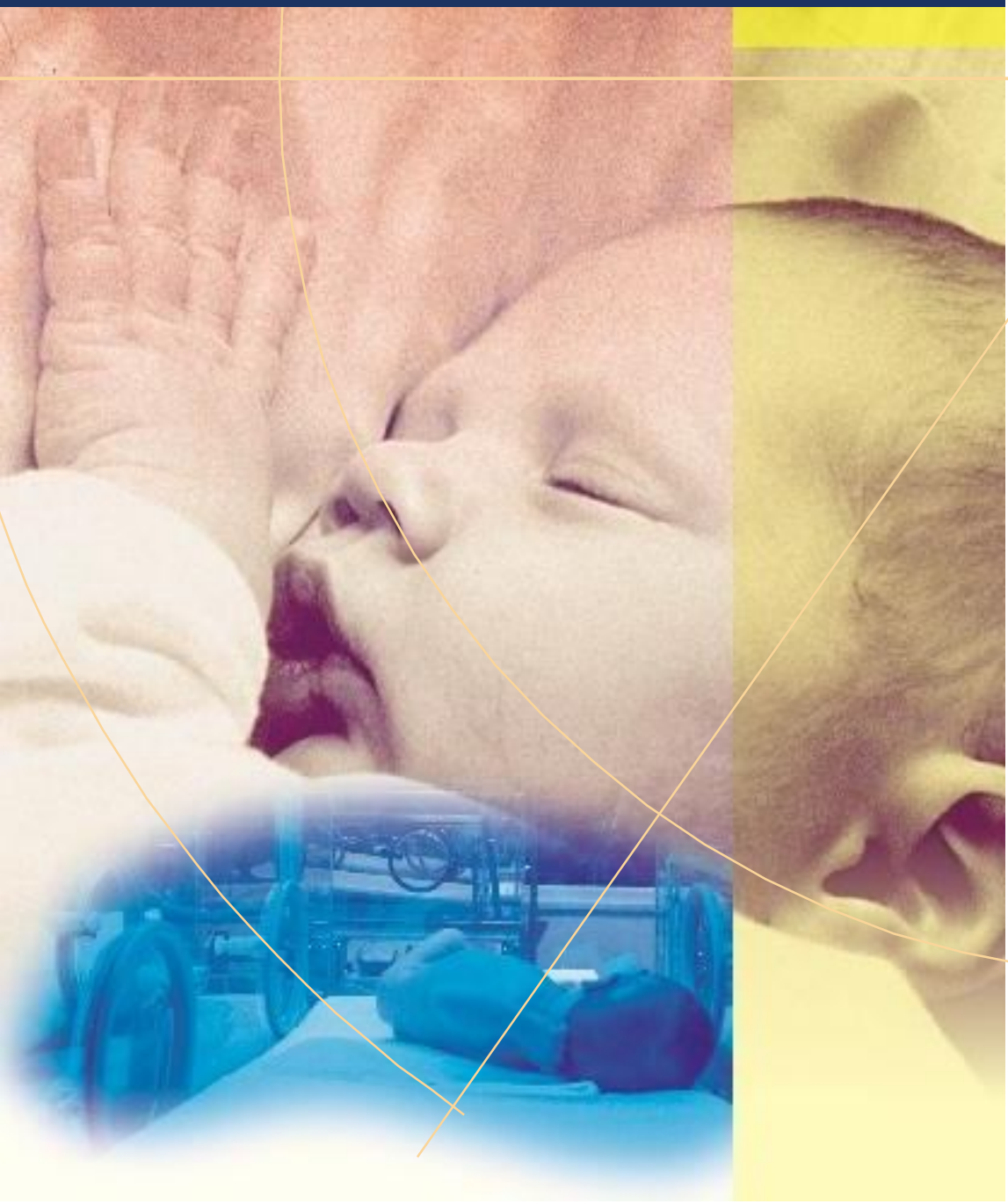
Vitamin D photosynthesis
By means of UV irradiation, the provitamin D7 (7-dehydrocholesterol) is transformed into pre-vitamin in the outer skin. In the process of hydroxilation in the liver and the kidneys, the bio-active form of vitamin D3 is formed, controlling the calcium metabolism and being hormonal in type.
Above all, vitamin D3 influences cellular information, cell differentiation, endocrine regulatory systems, immune reactions, macrophage functions as well as the myocardial metabolism. It is of practical use in avoiding rachitis, osteoporosis, osteomalacia, cancer of the colon, etc.

The active spectrum of UV-induced vitamin D is limited to the UV range below 320 nm.
Dosages are much lower than those causing sun-burn (equipment with TL/01, CLEO Natural, HPA filtered).

Further effects
In general, suberythemal doses of UV-B "light" have many bio-positive systemic effects on the human being, which can be used in prevention, in sports physiotherapy and in the rehabilitation of patients. Some of these effects are as follows: Vitamin-D synthesis in skin (prevention of rachitis, osteoporosis, etc.), enhancement of the metabolism in general, improvement of blood oxygen utilisation, enhanced phagocytic capacity of polymorphonuclear white blood cells l (16, 17). In many cases, these effects can be obtained from radiation with low doses (equipment with a small amount of UV-B in a solarium, thus making up for a possible shortage during the darker months with less sun (September to April).

Works photo Tomesa Specialist Clinic, Bad Salzschlirf (Germany).





The visible range of optical radiation is now also used for numerous applications in prevention and therapy as well as during the clinical test phase (effects only via the eye or via the skin/vascular system).

a. Phototherapy for hyperbilirubinemia
b. Phototherapy for winter depression (SAD), the jetlag syndrome, the shift-worker syndrom
c. Enhancement of vigilance (improvement of activity and concentration
d. Photodynamic therapy with red light

Hyperbilirubinemia (neonatal jaundice)
An example of phototherapy in the visible region is the treatment of hyperbilirubinemia with blue light (400-500nm). Unconjugated bilirubin, being a decomposition product of haemoglobin, is not fully soluble in water and plasma. In normal physiological circumstances, this unconjugated bilirubin is bound to albumin and transported to the liver where it is converted by glucuronyltransferase into the water-soluble conjugated form and excreted in the bile. When the albumin binding capacity of the plasma is exceeded (e.g. in icterus neonatorum, in Crigler Najjar syndrome, etc), the unconjugated bilirubin can diffuse into the tissues. Blue light can convert this unconjugated form into a more watersoluble form by a photo-oxidative process and an isomerization process (10, 11, 12).
Figure 10 (page 22) illustrates the spectrum of a blue lamp TL/52, just emitting at the maximum effective wavelength of 450 nm. The TL/03, emitting at a maximum of 420 nm, is slightly lower in efficiency (figure 9). The blue light component in halogen dichroic mirror lamps can also be used (UV and IR filtering is necessary). There has also been research showing the bilirubin content of the plasma being lowered with the help of green light ('TL'/50). However, the results are still not convincing enough to warrant a change from blue light.

SAD - seasonal affective disorder
Light therapy can also be used in a totally different field: in the so-called seasonal affective disorder (SAD) syndrome. The application of bright light (>2500 lux and high colour temperature) is an effective treatment for winter depression. It has been postulated that since bright light is capable of suppressing the hormone melatonin, this hormone moderates the effects of shortening days on symptoms of SAD in wintertime (13, 14, 15).
For this type of phototherapy, we recommend the fluorescent lamp TLD/930, 940, 950 "natural daylight". Consideration must be given not only to luminance (illuminance is a useful parameter) but also to other parameters (e.g. size of the radiated area on the retina) as well as safety aspects for equipment design.
There are also indications that this therapy is successful for treating jetlag and the shift-worker syndrome.

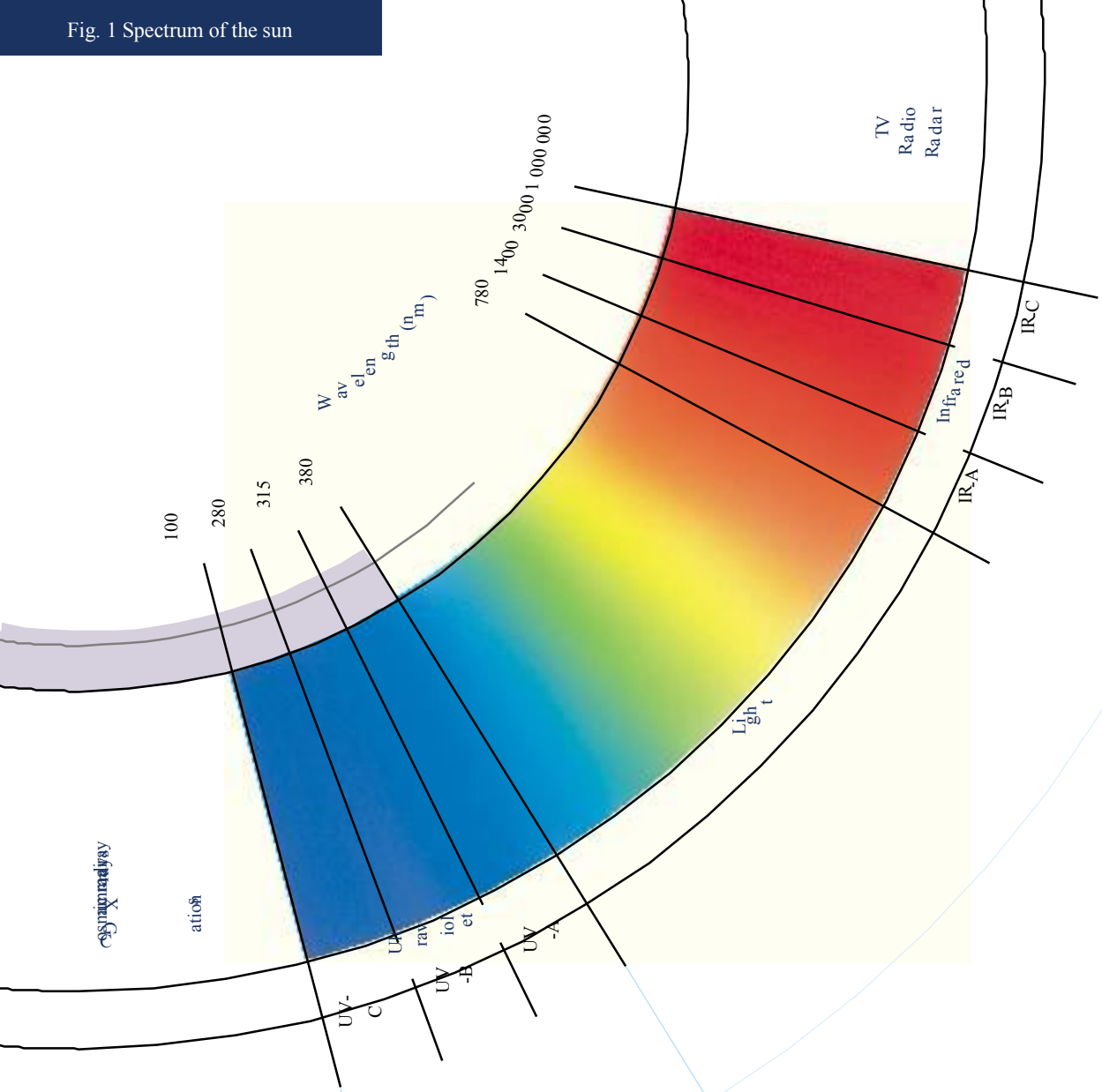
Further possibilities
In the field of photodynamic therapy, photo-oxidation of biological molecules occurs due to the presence of photosensitising pigments and oxygen. Photodynamic therapy of tumors with haemato-porphyrin derivates (HPD) and visible light in the 630 nm range is very promising. The photosensitising agent HPD is stored in the malignant tissue and subsequently kills off the tumor when exposed to 630 nm (red) light. Further promising photosensitising drugs for use in photodynamic therapy will most probably be the phthalocyanines with a high extinction coefficient between 650 and 780 nm,still in the range of the optical window (cf. also "Optical characteristics of the skin").
Appropriate radiation sources are f.i. filtered MSR-lamps or special fluorescent lamps with a radiation maximum around 630 nm.

For treatment with infrared light, Dr. Klinkhamer collected the following complaints:
a. Wound healing: for non-infected and infected wounds
b. Local inflammations: acute local inflammations of the skin, furuncles, carbuncles and (common) colds
c. “Fight” against pain: rheumatic disorders, bursitis, fibrositis, ischias, lumbago, myalgia (muscle pain), tendinitis, and burns
d. Local circulation disorders: ulcus cruris varicosum, Raynaud’s disease, erythroderma, acrocyanosis and chillblained hands and feet
e. Resorptice processes: sprains, contusions, edema and haemorrhages
f. Dentistry: pelpitis acuta, peri-odontitis, peri-apical inflammations, dentitio dificilis, arthrosis of the temporomandibular joint and treatment of pain after extraction.

More recent studies reveal positive indications in the case of hypertension (16, 17, 19, 20, 21) and in cancer therapy according to the hyperthermia multistage process after M. v. Ardenne (20). Infrared whole-body radiation (e.g. in IR cabins) uses the knowledge that, of all types of optical radiation, short-wave infrared (IR-A) penetrates deepest in the body by 1000 nm. The result can be a targeted expansion of the vessels or, on increasing the core temperature by 1 to 2ºC, a desired perspiration effect. The medium and long-wave infared should be reduced to a minimum (e.g. by filtering).

Most of all, infrared/infraphil lamps and (filtered) halogen and quartz tube lamps with a sufficiently high colour temperature (~2800 K) are used as suitable IR light sources (cf. also point 6).

Fig. 1 Spectrum of the sun



4 THE CHARACTERISTICS OF OPTICAL RADIATION

The spectrum of optical radiation (Fig. 1) lies between 100 nm (in the UV range) and 1 mm (in the IR range). For practical purposes, this wavelength range is subdivided into seven bands in accordance with CIE (International Commission on Illumination)
UV-C from 100 to 280 nm (short-wave UV)
UV-B from 280 to 315 nm (medium-wave UV)
UV-A from 315 to 380(400) nm (long-wave UV)
Light (visible radiation) from 380(400) to 780 nm
IR-A from 780 to 1400 nm (short-wave infrared radiation)
IR-B from 1.4 to 3 µm (medium-wave infrared radiation)
IR-C from 3 µm to 1 mm (long-wave infrared radiation).

Not only ultraviolet "light" but also visible and infrared "light" have many possible applications in photobiology and photomedicine. Ultraviolet, visible and infrared radiation have distinctive physical, photobiological and photochemical features. Going from the infrared towards the ultraviolet region; the energy content (photon energy) of the "light" increases.
Most photobiological effects in the ultraviolet and visible region are due to photochemical reactions, whereas effects in the infrared region are mostly due to heat dissipation.

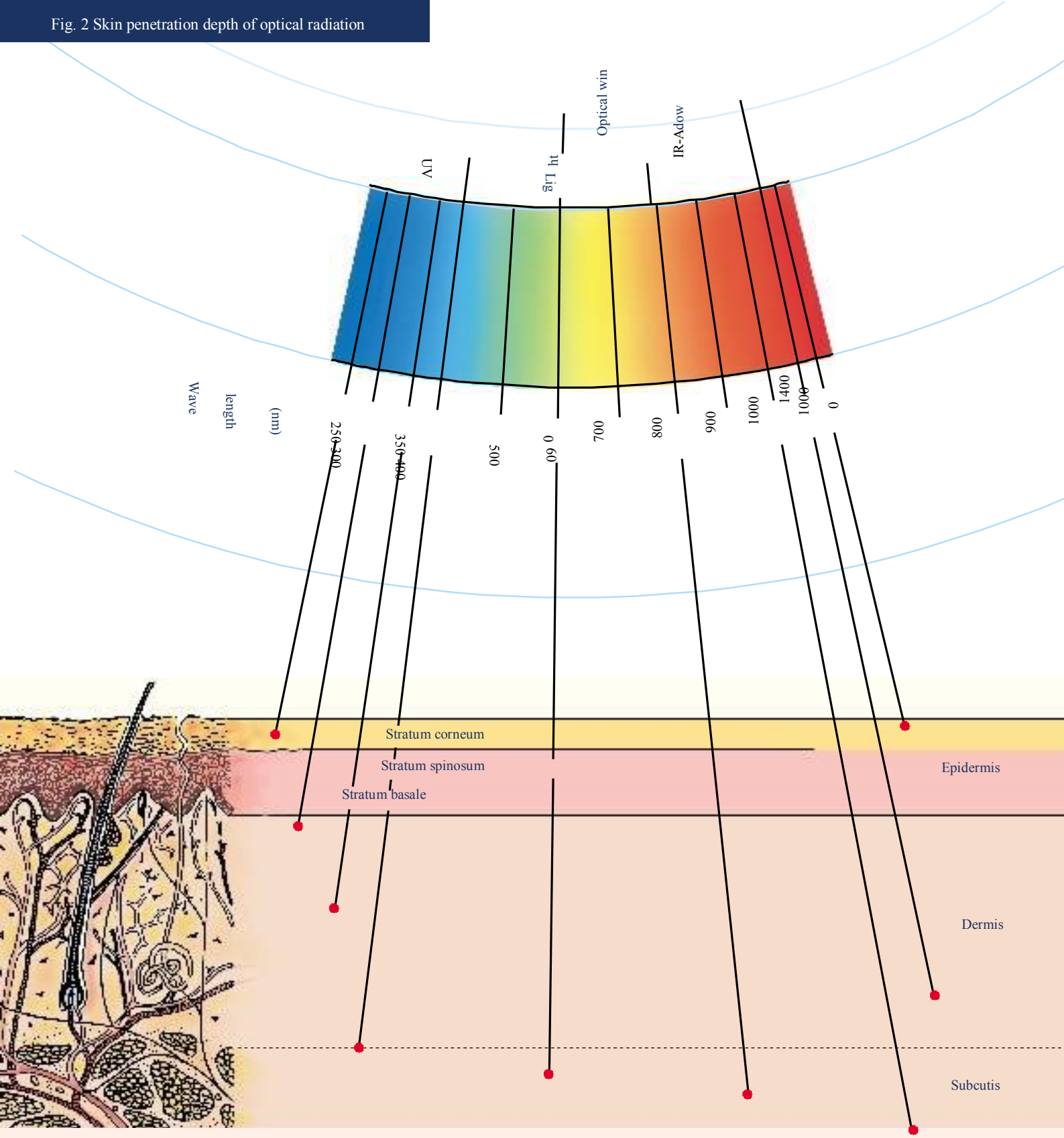
Photochemical reactions are controlled by several basic laws of which the most important are the following:
According to the Draper-Grotthus law, interaction between "light" and matter can only occur if the "light" is absorbed by the matter involved. If this is not the case, then the radiation will be reflected or transmitted or scattered.
The second law known as the Bunsen-Roscoe law or reciprocity law states that the quantity of the reaction products of a photochemical reaction is proportional to the product of the irradiance of the "light" and the exposure time. This product is called the dose.

Also in photobiology the effect depends on the dose rather than the intensity of the light. The same dose (with the same effect) can be provided by a high intensity in a short time or a low intensity in a long time.
So if "light" is absorbed by, for example, the skin, the resulting effect is dependent on the exposure dose rather than the irradiance level. In photobiology this is called the "dose-response" relation for a particular effect.

As stated before, optical radiation can only be effective if absorbed by so called chromophores within the matter involved. These chromophores can be biological molecules like DNA, RNA, proteins or drugs. The absorbed ultraviolet or visible "light" can break or change a chemical bond in a molecule, or create bonds between two or more molecules.

Absorbed infrared radiation excites rotational or vibrational energy levels in a molecule: it is a photophysical reaction. This absorption leads to heat dissipation in the absorbing matter. This warming effect is used in many medical applications like thermotherapy, hyperthermia and in sports physiotherapy. However, it can also be an unwanted side effect (depending on the wavelength).

Fig. 2 Skin penetration depth of optical radiation



5 THE OPTICAL PROPERTIES OF THE SKIN

A knowledge of the optical properties of the skin is indispensable for understanding the effects of optical radiation.
Optically, the skin can be regarded as an inhomogeneous medium consisting of four layers:
- Stratum corneum
- Stratum spinosum, incl. stratum basale } Epidermis (50 - 150 µm thick)
- Dermis (0.8 - 1 mm)
- Subcutis (1 - 3 mm)

These layers have different refractive indices and distributions of chromophores, which will bring about different reflecting, transmission and scattering characteristics depending on the wavelength.
Figure 2 gives a schematic representation of the skin layers and the depth of penetration as a function of the wavelength.

The reflection of radiation in the 250-300 nm region both against and in the stratum corneum is about 4-7%. Towards the longer wavelength the reflection of the skin increases. At about 800 nm there is a maximum reflection of 40-60% depending on the skin type. Going further towards the IR the reflection decreases to an average value of 5-10% in the IR-B region.
The degree of reflection is also dependent on the melanin content; the darker the skin, the less the radiation will be reflected, especially in the visible region. Refraction of the radiation is mostly the result of the structure of the stratum corneum, while scattering is the result of interaction between the light and the particles according to the wavelength of the light.
The attenuation of radiation in the epidermis is primarily due to absorption by chromophores and, secondly, by scattering.
The chromophores in the stratum corneum are predominantly melanin, urocanic acid and proteins consisting of aromatic aminoacids like tyrosine and tryptophan.
The stratum malpighi, consisting of viable cells (keratinocytes), has the same chromophores as the stratum corneum, but here the nucleic acids of DNA and RNA play an important role in absorbing short-wave UV. The absorption behaviour and reaction of the skin to UV exposure differs considerably depending on the particular individual. Six skin types (four light-skin, two dark-skin types) have been defined in a commonly used international classification based on erythema formation and pigmentation capability of the skin when exposed to sunlight.

The penetration of "light" into the dermis, because of the vascularization, is also influenced by the radiation absorbance of the blood (haemoglobin and oxyhemoglobin) in the 400-600 nm region and by the scattering of collagen fibres.
In Figure 2 it can be seen that the greater part of UV-C is absorbed in the stratum corneum (90%) and that 90% of the UV-B is absorbed in the epidermis but that a considerable part of the UV-A can reach the dermis which contains blood vessels. The thin epidermis has no blood vessels of its own, but receives what it needs from the capillary blood vessels immediately below the basal-cell layer of the epidermis.
Light with a wavelength between 600 and 1400 nm (red light, short-wave infrared) can penetrate into the subcutis and is therefore called the "optical window" of the skin.

6
ARTIFICIAL LIGHT SOURCES (lamps)

Artificial light sources can be divided into the following groups:

Incandescent lamps:	Gas-discharge lamps:
- normal lamps	- low-pressure lamps
- halogen lamps	- medium-pressure lamps
- infrared lamps	- high-pressure lamps

Although lasers, LEDs (light-emitting diodes) and LCDs (liquid crystal displays) also belong to the group of sources producing optical radiation, they will not be described in this brochure since their technology and application are totally different from those of "lamps".

The basic principles of lamps will be briefly explained in the following (for detailed technical information concerning light and radiation sources and optimum application thereof in equipment, please contact Philips Lighting, addresses on page 28).

Fig. 3

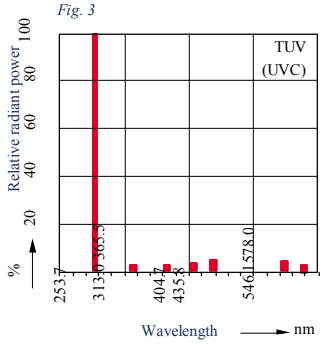


Fig. 4

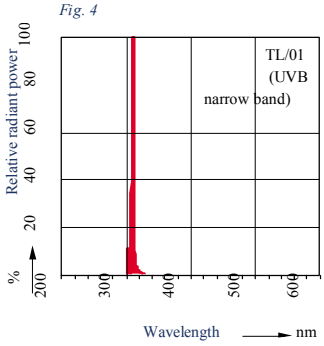


Fig. 5

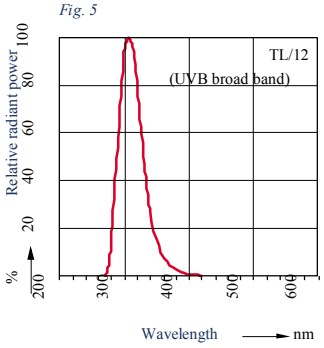


Fig. 6

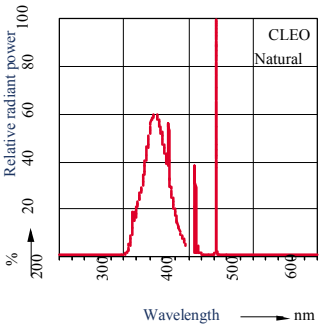


Fig. 7

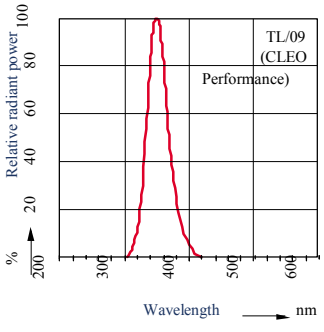
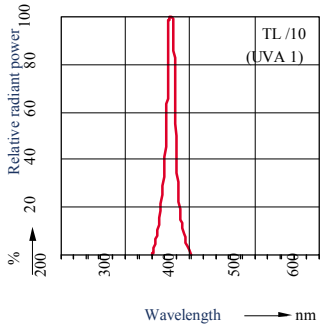


Fig. 8



Gas-discharge lamps
A gas-discharge lamp is based on an electrical discharge through a gas or vapour. In most cases the discharge is sustained by the ionization of mercury vapour or, in other cases, by inert gases like Xe, Ar and Ne. Depending on the mercury vapour pressure these lamps can be divided into:
- Low-pressure
- Medium-pressure gas-discharge lamps
- High-pressure

The emitted spectrum of these lamps changes from low- to high-pressure due to the increased population of the higher energy levels of mercury. In consequence, the emitted energy distribution is shifted from the high photon energy lines (185 and 254 nm) towards the lower photon energy lines, i.e. towards the UV-A range and the visible part of the spectrum.
With the increasing mercury pressure we also get a broadening of the emission lines due to the influence of atoms or ions close to the excited atom during its emission of radiation.

Low-pressure mercury lamps (without fluorescent layer)
Tubular germicidal lamps ("TUV") belong to the group of the low-pressure lamps.The germicidal "TUV" lamp (Fig. 3) emits about 95% of its energy in the 254 nm mercury line. The action spectrum for inactivation of micro-organisms has its maximum at about 265 nm (DNA absorption) and therefore this lamp type is mostly used for sterilization and disinfection.

Many of these lamps are used, as an alternative to chlorine, for the disinfection of drinking water and waste water. Also, air contamination in operating theatres (for longer operations) can nowadays be reduced to well below the suggested upper limit for ultraclean air systems (10 cfu/m^3) by combining the use of "TUV" lamps (UV-C) and occlusive working clothes, which is a very cheap solution to the problem.

Fluorescent lamps
Fluorescent lamps ('TL') are also low-pressure mercury lamps with a fluorescent layer on the inside of the glass envelope which transforms the short-wave ultraviolet energy of the gas-discharge into useful radiation depending on the type of phosphorus. It is well known that for illuminating purposes many types of phosphorus are available.

In the UV-B region, the 'TL'/01 and 'TL'/12 lamps are used in phototherapy and the spectra are presented in Figures 4 and 5,respectively.
In the UV-A range, three lamps are available with a maximum emission at 350 nm (CLEO Natural, CLEO Performance) and at 370 nm ('TL'/10). These lamps are primarily used in photochemotherapy but also in phototherapy, e.g. for neuodermatitis. The spectra are presented in Figures 6, 7 and 8,respectively.
The later two lamps are also available with built-in reflectors coded as 'TL'/10R, CLEO Natural R and CLEO Performance R. Since an external reflector has now become unnecessary, the lamps can be mounted closer together in order to increase the irradiance level (up to two-fold increase in comparison with systems with an external reflector) and consequently provide shorter treatment times.

Note: The lamp type designations may change - please request up-to-date information.

Fig. 9

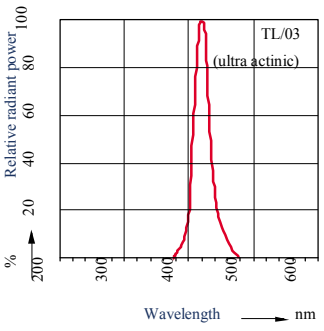


Fig. 10

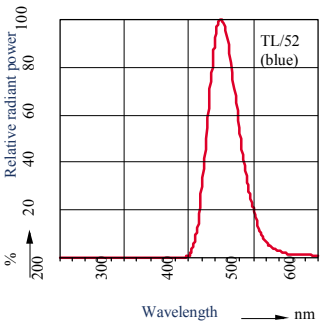


Fig. 11

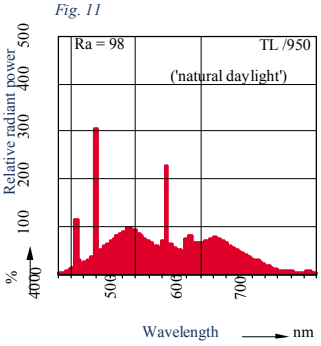


Fig. 12

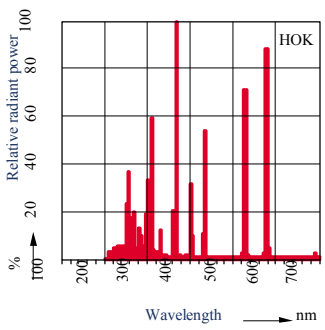


Fig. 13

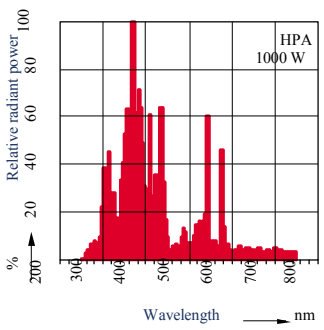
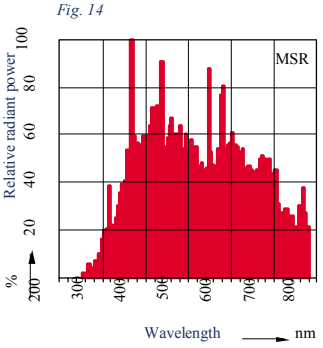


Fig. 14



In the visible region, two other lamps used in the phototherapy of hyperbilirubinemia must be mentioned: the 'TL'/03 with the peak emission at 420 nm and the 'TL'/52 with the maximum wavelength at 450 nm (Figures 9 and 10).
For the treatment of seasonal affective disorder (SAD), we strongly recommend the use of TLD/940, 950 lamps (Fig. 11) with 6500 K colour temperature ("Natural Daylight"), preferably in combination with high-frequency electronic gear.

Medium-pressure mercury lamps
The spectrum of a medium-pressure mercury lamp (HOK, HTK, HOQ, HPK) without additives is presented in Figure 12. A modified version of this lamp ("HOK") is used in monochromator-like equipment to determine the skin sensitivity in the UV and visible region (photodermatosis).

Metal-halide lamps
In medium-pressure lamps with additives like iron and cobalt halides, the emission is due to the excitation of these additives rather than the mercury. These HPA lamps (Fig. 13) are provided with special filters, and are used in phototherapy and photochemotherapy (usually with additional filtering. Virtually any spectrum can be enhanced by the addition of various metal halides, in the UV as well as in the visible range (MSR, HPI, etc.) (Fig. 14).

High-pressure and very high-pressure discharge lamps
The range of high-pressure lamps ("CSX" lamps with xenon and "CS" lamps with mercury) which are compact-source lamps can be regarded as point sources and are usually applied in irradiation monochromators in photobiological research.

Filtering
Because of their fluorescing abilities, UV-A gas-discharge lamps with Wood's glass envelopes - so-called "blacklight blue" lamps (types "HPW", "MLW" and 'TL'/08) - which emit only UV in the 365 nm region (without visible light) can play an important role in the diagnosis of skin diseases like tinea capitis, pityriasis alba and vitiligo. These lamps are also used in the treatment of, for example, palmar psoriasis and alopecia areata.
Whereas fluorescent lamps usually do not have to be filtered additionally in order to eliminate unwanted radiation components, this is still frequently necessary with medium-pressure and high-pressure lamps, depending on the specific application and requirements relating to the desired spectrum. The filters have to meet high demands (incl. temperature resistance, low spectral transmission scatter, high spectral stability throughout service life).

Equipment design
As the radiation is used primarily for treating surfaces, the radiation energy produced in the lamps must be directed by means of reflectors. The desired spectrum, necessary intensity, area to be treated, size and angle of incidence determine the type and quantity of the radiation source, the form and material of the reflector and the choice of filter. The lamps must always be operated under the operating conditions specified by the lamp manufacturer (cooling, ballasts, etc.). Safety regulations and official instructions as well as workplace protection requirements must be observed when UV and IR lamps are used (these differ from country to country).

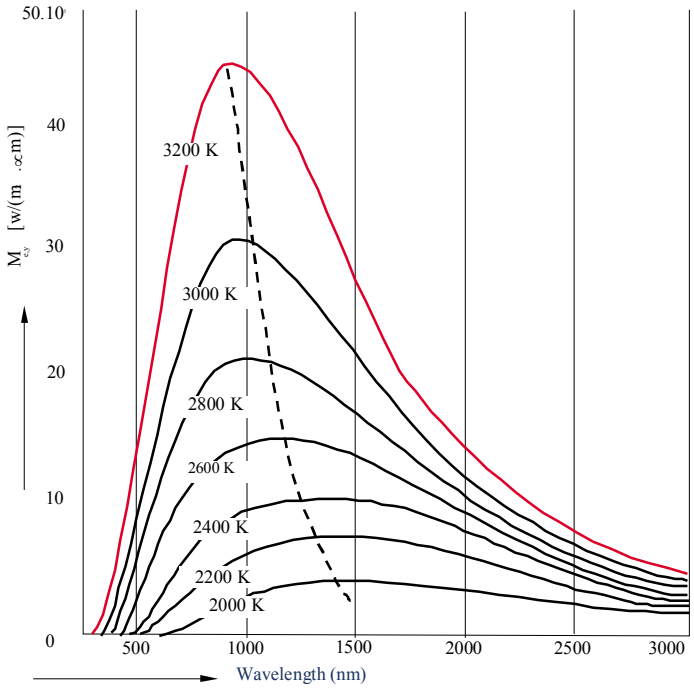

50.10
40
30
20
10
0
M_{λ_0} [w/(m ·cm)]
3200 K
3000 K
2800 K
2600 K
2400 K
2200 K
2000 K
500
1000
1500
2000
2500
3000
Wavelength (nm)

Fig. 15

Incandescent lamps, halogen lamps, IR lamps

The incandescent lamp produces optical radiation by electrically heating a tungsten filament according to Planck's law (Fig. 15). The radiation flux is a function of the absolute temperature. The spectral radiation flux also depends on the wavelength. The maximum radiant flux increases rapidly with the operating temperature, while the wavelength at which the maximum occurs becomes shorter.

Increasing the temperature of the tungsten filament will result in a higher evaporation of the tungsten from the filament. This can be reduced by filling the lamp with an inert gas or a combination of an inert gas and nitrogen.
A special case arises when halogen compounds are added to create a cycle which redeposits the evaporated tungsten on the filament. This is the basic principle of the halogen lamp which can operate at a higher temperature and consequently will emit part of the radiation in the UV region.

Examples of incandescent lamps (there is a wide range of lamps differing in form, rating, geometry available) used for prevention and therapeutic use are the familiar "Infraphil" lamps. These lamps have a filament temperature of 2800 K and the peak wavelength lies around 1000 nm. The red-fronted blown-bulb (Infraphil/Infrared R95E) and pressed glass (Infraphil/Infrared PAR 38E) infrared reflector lamps are specially designed for heat radiation equipment in therapeutic applications like the treatment of rheumatism, lumbago, neuralgia and in sports physiotherapy.
The red filter in front of these lamps cuts off the light below 600 nm in order to diminish radiation which would be absorbed by the haemoglobin of the blood (prevention of haemolysis).
Halogen lamps are now also available in a wide range of different geometric, design and rating versions. In general, filament temperatures are between 2800 and 3200 K. The energy content in the visible and infrared range increases as the colour temperature rises. Lamps with dichroic mirrors (infrared-diminishing) or aluminium reflectors (infrared-reflecting) can be used depending on the particular application.
For the treatment of larger areas, Philips infrared halogen heat lamps ("IRK" lamps) represent a good solution for treatment involving heat (heat transmission by means of radiation). These tubular lamps are available in 500, 1000 and 1500 Watt versions, and can be mounted in appropriate luminaires.
If medium-wave and long-wave infrared radiation represents a problem in certain photobiological applications (absorption in the upper most layers of the skin), it can be eliminated by means of dichroic mirrors, IR filters or water filters.

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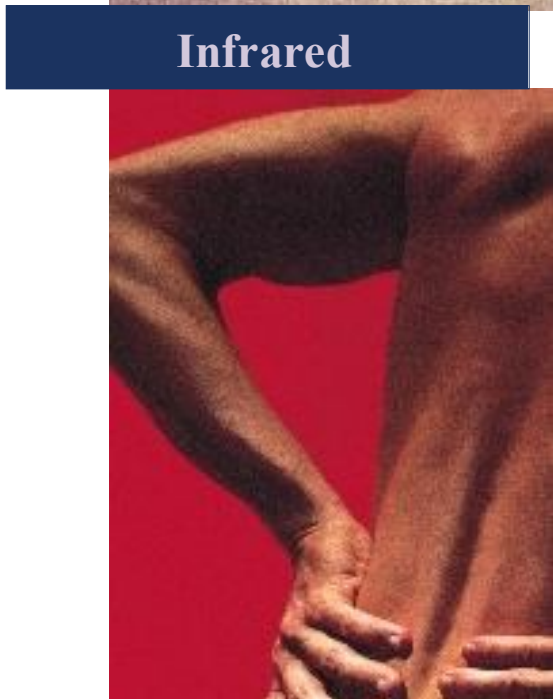

Fields of application and lamps

			Philips-Radiation sources
Indications in the ultraviolet region	**Wavelength region [nm]**	**Wavelength max [nm]**	
Effects on/via the skin			
Building up sun protection	280 - 380	300	TL 'CLEO-Natural', HPA (filtered)
Vitiligo, phototherapy of	280 - 350	310, UV-B	TL/12, TL/01
Polymorphous light erruption, conditioning of	280 - 380	315	CLEO Performance, +TL/01 (TL/12)
Psoriasis phototherapy (SUP)	300 - 320	310	TL/01, TL/12, HPA (filtered), CLEO Natural
Acne phototherapy	300 - 400	UV-A, UV-B	HPA (filtered)
Atopic eczema, phototherapy of	300 - 400	individual/variable	TL/10 (filtered), CLEO Performance, TL/01
PUVA photochemotherapy (psoriasis and others)	320 - 380	330.... 350	CLEO Performance, HPA filtered
Photopheresis	250 - 400	330 ... 350	TL/08, CLEO Performance
Photoreactivation	350 - 480		TL/10, (TL/03, TL/52)
UV-blood irradiation	UV-C, UV-B, UV-A, Blue light	254, 306, 370, 460	PL-TUV, PL/12, PL/10, PL/52
Application in physical medicine			
Photosynthesis of vitamin D3	255 - 320	295	TL/01, CLEO Natural
Phagocytosis, improvement in	300 - 380	350	CLEO Performance
Heart/cardiovascular system, positive stimulation of	300 - 400	300	CLEO Natural, CLEO Professional
Blood fluidity, improvement of	300 - 380	350	CLEO Performance
Cholesterol, lowering of	320 - 400	370	CLEO Performance, TL/10
Blood irradiation	UV-C, UV-B, UV-A, Blue light	254, 306, 370, 460	PL-TUV, /12, /10, /52

Indications in the visible region (light)	**Wavelength region [nm]**	**Wavelength max [nm]**	**Philips Radiation sources**
Effects via the eyes/ via the skin			
SAD-Saisonal effective disorder (also jetlag-, shiftworker syndrome, PMS syndrome); improvement vigilance and activity, influence on circadian rhythm	400 - 780 (without UV)	continuous	TL/96, /95 'Nat.daylight' /HF-operation TL/840, 850 (R) /HF-operation
Coloured light phototherapy (eyes, skin)	blue, green, yellow, red	460, 535, 580, 660	TL/18, /17, /16, /15
Orange light phototherapy	580 - 630	600	TL/16, solid rad. 2200K (IR filtered)
Helio phototherapy (eyes, skin)	light	continuous	MSR-lamps (filtered)
Effects via/on the skin			
Photoreactivation	350 - 480	±400	TL/03, TL/52 (TL/10)
Newborn icterus, phototherapy	420 - 520	460	TL/52, PL/52, TL/03, Spec.Blue
Coloured light phototherapy (eyes, skin)	blue,green,yellow, red	460, 535, 580, 660	TL/18, /17, /16, /15
Acne-phototherapy (propioni bact.)	blue, green		HPA, HID, green, TL spec.
PDT-photodynamic therapy	600 - 800	630 (and others)	HID-red (= f (Sensibil.), MSR
Helio-phototherapy (eyes, skin)	UV + light + IR	continuous	MSR lamps (filtered)

Indications in the infrared region	**Wavelength region [nm]**	**Wavelength max [nm]**	**Philips-Radiation sources**
Effects via the vascular system			
Therapy of hypertension	800 - 1400	1000	Halogen lamp, > 2800K, (IR-B/C = eliminated)
Tumor therapy (hyperthermia)	800 - 1400	1000	Halogen lamp > 2800K, (IRB/C = eliminated)
Treatment rheumatic desease	800 - 1400	1000	Infraphil/Infrared
Effects on/via skin			
Wound treatment/healing	1400 - 2000		IRK, filtered, (light), hal. caps.
General warming up	1000 - 3000		IRK, Rubin
Effects via skin and vascular system			
Infrared sauna	800 - 2000	1000/1500	Halogen lamp 2700 - 2800K